

*Space Technology Mission Directorate
Game Changing Development Program
2017 1st Quarter Review*

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National Aeronautics and
Space Administration



Advanced Manufacturing Technology

Presented By: John Fikes

January 2017

TECHNOLOGY DRIVES EXPLORATION



AMT Project Manager Annual Assessment



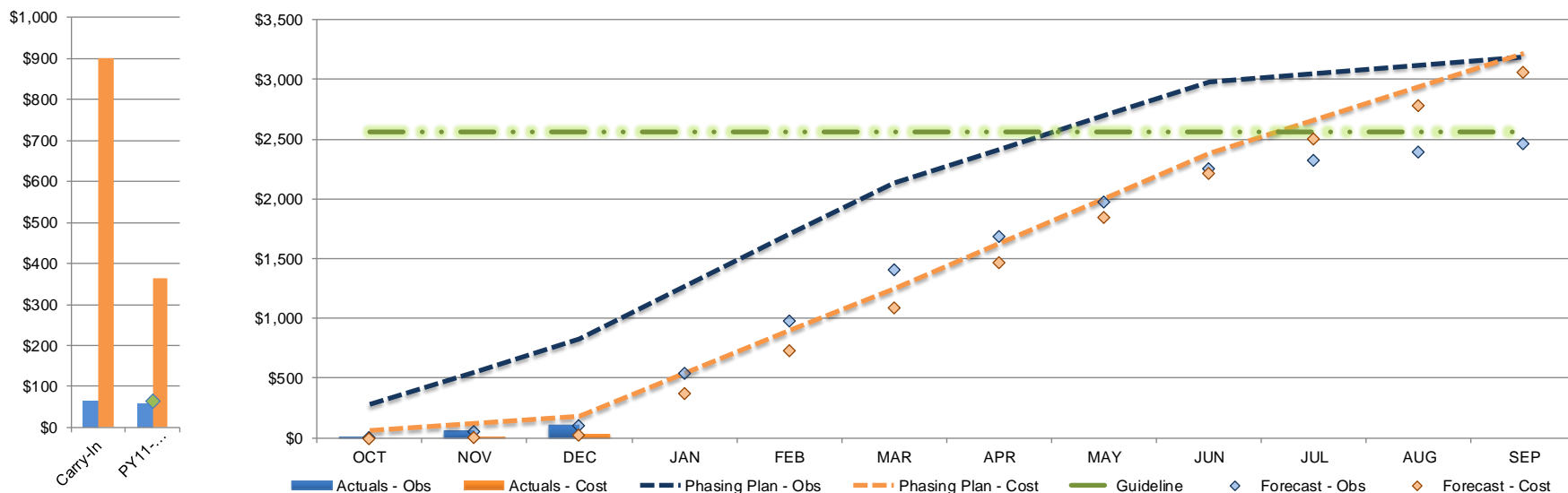
Technology	Performance				
	T	C	S	P	
Low Cost Upper Stage Class Propulsion					<p>Technical is yellow due to the EBF³ process to add an inconel structural jacket to the GRCop-84 liner is producing cracks along forward and aft ends at the inconel/GRCop-84 interface. Currently implementing trial on Unit 2.1 as part of the approved recovery plan.</p> <p>Cost is yellow due to the new recovery plan requiring more resources at LaRC. Project is carrying as a “threat” for now. Actual increase will not be realized until later in FY17.</p> <p>Schedule is yellow due to minimum schedule reserves in current plan approved by change request.</p>
Additive Construction with Mobile Emplacement (ACME)					<p>Technical is yellow due to on-going challenges to meet the U.S. Army Corp of Engineers (USACE) requirements with their current material (3/8th inch aggregate). Schedule is yellow due to minimum schedule reserves for meeting ACES 3 hardware deliverables.</p>



Resources: Non-Labor Obligations and Cost



FY 2017 Non-Labor Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out
Obs	Guideline		65.0	2,559.0	2,559.0	2,559.0	2,559.0	2,559.0	2,559.0	2,559.0	2,559.0	2,559.0	2,559.0	2,559.0	2,559.0	
	Phasing Plan (RLP)			276.5	553.0	829.5	1,265.4	1,701.2	2,137.1	2,417.1	2,697.0	2,977.0	3,046.7	3,116.3	3,186.0	(621.6)
	Actuals	65.0	59.6	11.8	52.3	106.7										
Cost	Forecast			11.8	52.3	106.7	542.6	978.4	1,414.3	1,694.2	1,974.2	2,254.2	2,323.8	2,393.5	2,463.2	101.3
	Phasing Plan (RLP)			61.0	122.0	183.0	538.7	894.4	1,250.1	1,626.9	2,003.6	2,380.4	2,661.0	2,941.7	3,222.3	555.0
	Actuals	901.3	364.1	0.0	7.2	23.9										
	Forecast			-	7.2	23.9	379.6	735.3	1,091.0	1,467.8	1,844.5	2,221.3	2,501.9	2,782.6	3,063.2	(8.7)

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

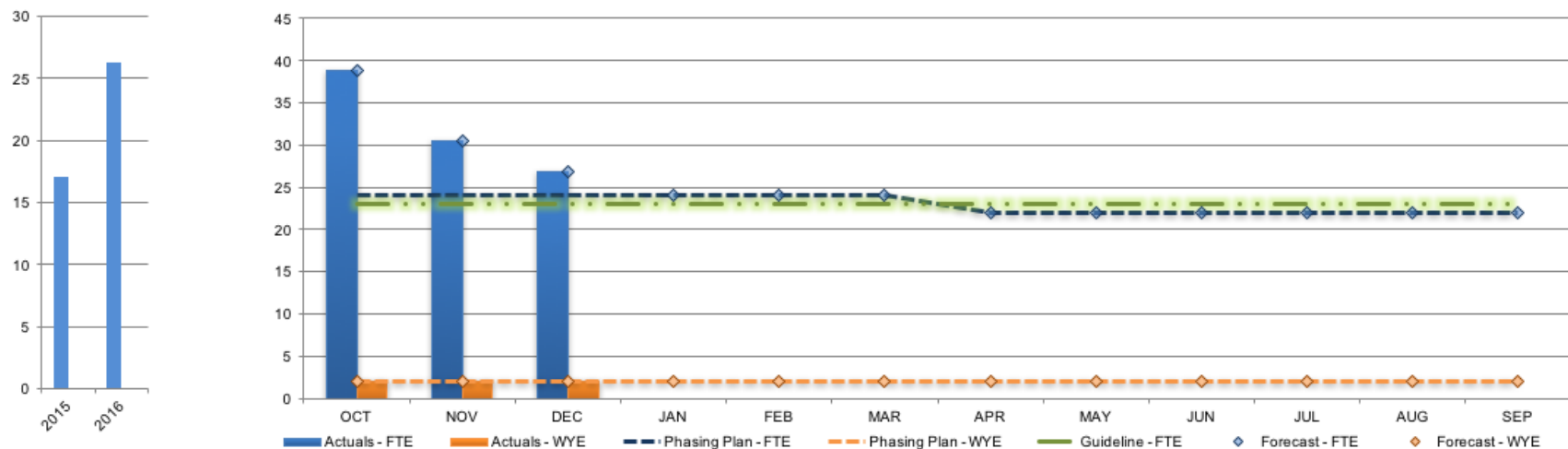
	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing \$ 830	Currently operating under CR thru April 2017. Contractual commitments/obligations are on-going and are expected to start catching up during the 2 nd quarter of FY2017. Project activities on-going and there have been no impact to project milestones.
	Actuals \$ 107	
	Variance \$ (723)	
'17 Cost	Phasing \$ 183	Currently operating under CR thru April 2017. Project utilizing uncosted FY2016 carryover for management support activities. Project activities on-going and no impact to project at this time.
	Actuals \$ 24	
	Variance \$ (159)	



Resources: Total Project Workforce FTEs/WYEs



FY 2017 Workforce Status



	Incremental	2015	2016	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	2017 Avg
FTE	Guideline			23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0
	Phasing Plan (RLP)			24.0	24.0	24.0	24.0	24.0	24.0	22.0	22.0	22.0	22.0	22.0	22.0	23.0
	Actuals	17.0	26.3	38.8	30.6	26.8										32.0
	Forecast			38.8	30.6	26.8	24.0	24.0	24.0	22.0	22.0	22.0	22.0	22.0	22.0	25.0
WYE	Phasing Plan (RLP)			2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	Actuals	0.0	0.0	2.0	2.0	2.0										2.0
	Forecast			2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 FTE	Phasing	24.0
	Actuals	32.0
	Variance	8.0
'17 WYE	Phasing	2.0
	Actuals	2.0
	Variance	-



AMT Milestones and Forward Plans



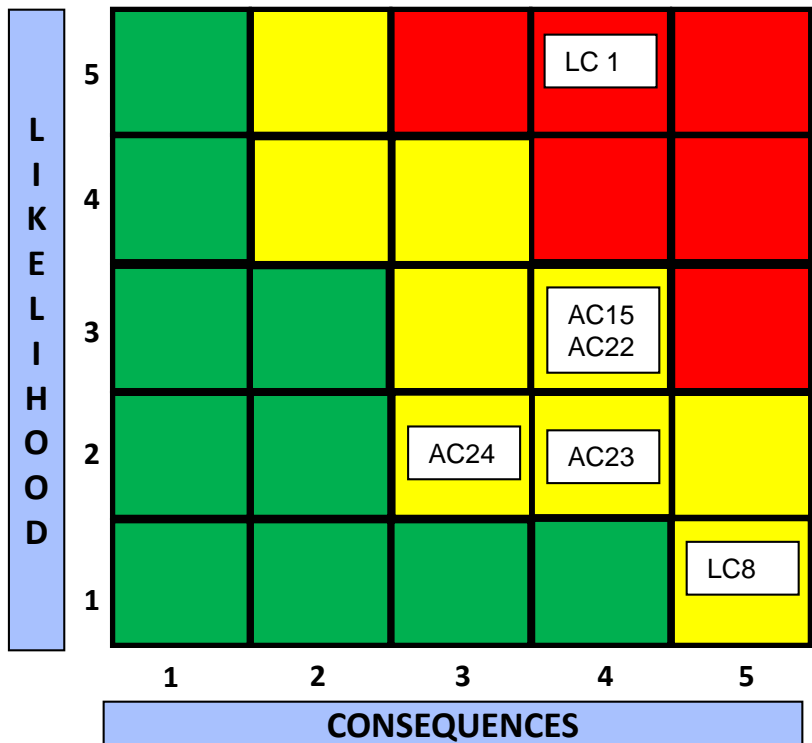
FY17 Key and Controlled Milestones		Baselined or Current Approved Completion Date	Actual Completion Date	Estimated Completion Date	Variance Explanation
FY17 Q1 (Oct 1 through Dec 31)					
ACME	ACME (Zero Launch Mass In-Situ (ZLM) Construction) Materials Development (KSC & MSFC)	12/30/16	12/30/2016(A)		
ACME	Completion of Environmental Modeling Analyses	12/31/16	12/31/2016(A)		
FY17 Q2 (Jan 1 through March 31)					
ACME	ACES 3 Gantry Design & Fabrication Complete	12/30/16		2/27/17	Lack of maturity of preliminary design drawings at CDR that slowed procurement efforts, Delays in electrical drawing initiation that slipped completion of electrical design by 1-2 weeks, Fabrication to Issued Release drawings rather than preliminary drawings delayed fabrication start by ~ 1 week, A late change to nozzle configuration to aid in manufacturing resulted in changes/delays to Boom piece-part design drawings.
ACME	ACME (Zero Launch Mass In-Situ (ZLM) Construction) Material Print Head Demonstration	1/31/17		3/31/17	Slip due to late motor delivery and weather delays.
ACME	Feedstock Processing/Transport Hardware Demonstration	1/31/17		3/31/17	Slip due to late motor delivery and weather delays.
ACME	Print Head Integration with Mobility System (KDP 3)	3/31/17			
ACME	Full Scale Optimized Planetary Structure Demos with Integrated Systems at a Lab or Planetary Analog (local) Site	3/31/17			
ACME	Integrated Excavation and Handling System Test	3/31/17			
LCUSP	Mechanical Testing Complete - SLM Deposited GRCop-84 (2nd Buy)	3/31/17			
LCUSP	Standardized NDE Techniques for Flight HW Documented	3/31/17			
LCUSP	Standardized SLM Process for Flt HW Documented	3/31/17			
FY17 Q3 (Apr 1 through June 30)					
LCUSP	Mechanical Testing Complete - SLM Deposited GRCop-84 for Orientation & Size Study*	6/22/17			
FY17 Q4 (Jul 1 through Sep 30)					
LCUSP	Begin Hot Fire Test - Chamber	7/26/17			Per Change Request submitted to GCD on 12/16/16.
LCUSP	Complete Chamber Hot Fire Test	8/15/17			Per Change Request submitted to GCD on 12/16/16.
LCUSP	Hot Fire Test (Integrated Assembly)	8/16/17			Per Change Request submitted to GCD on 12/16/16.
LCUSP	Integrated Hot Fire Test	8/16/17			Per Change Request submitted to GCD on 12/16/16.
LCUSP	Complete Integrated Hot Fire Test	9/12/17			Per Change Request submitted to GCD on 12/16/16.
ACME	Complete Full Scale Demonstrations	9/30/17			

Green = Controlled Milestone

Bold Black = Key Milestone



Risk Summary



ID	Trend	Approach/ Affinity	Risk Title
AC15	↓	W/Sc	Facility Operating Space
AC19		M/T	Safety Keep Out Zones CLOSED
AC20		M/Sc	Integration, Testing Space (Weather Impacts) CLOSED
AC21		M/T	Hose Management CLOSED
AC22	↑	Sc/C	Logistics for Fabrication, Assembly, Integration
AC23	→	T	Nozzle Development and Test
AC24	→	T	Accumulator Development and Test
LC1*		M/T,C,Sc	EBF3 weld technology
LC8*		M/T	GRCop-84 and Inconel625 Interface flaws

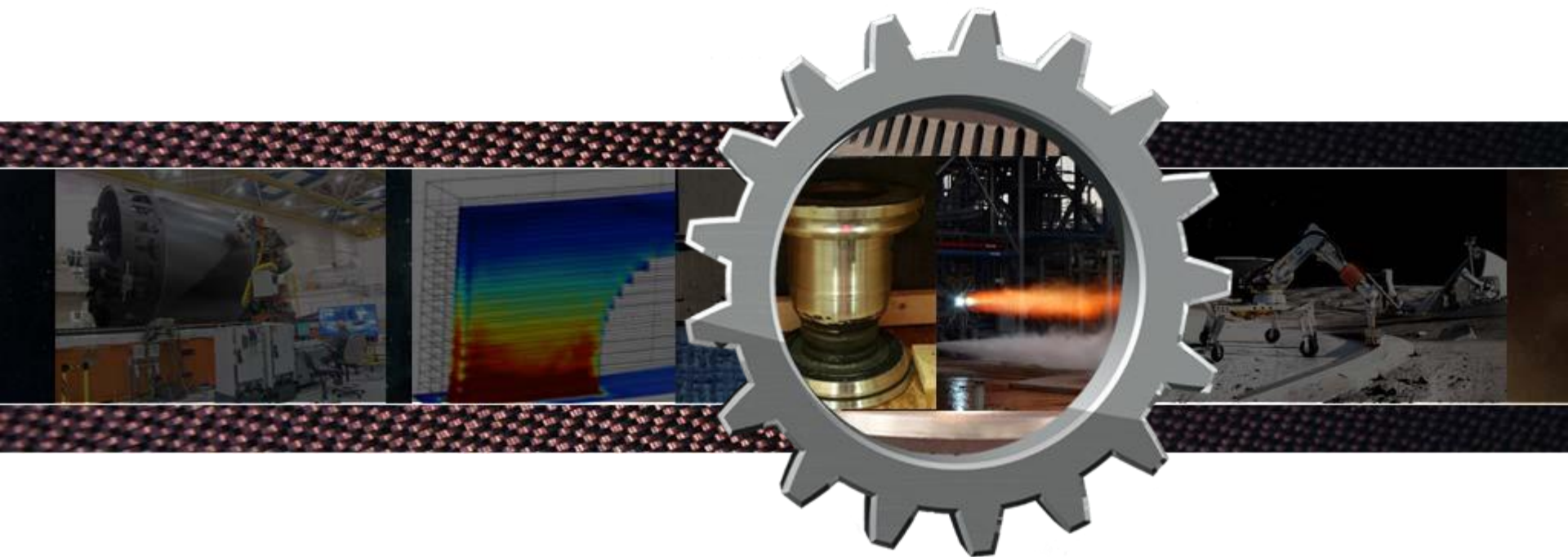
only high and medium risks are shown on summary chart

* LCUSP risks currently under revision

Criticality	L x C Trend	Approach
High	↓ Decreasing (Improving)	M - Mitigate
Med	↑ Increasing (Worsening)	W - Watch
	→ Unchanged	A - Accept
Low	□ New Since Last Period	R - Research
	Affinity: T-Technical C-Cost Sc-Schedule - Sa-Safety	



Low Cost Upper Stage-Class Propulsion





Advanced Manufacturing Technology LCUSP Overview



The LCUSP will demonstrate the ability to produce a low cost upper stage-class propulsion component system using additive manufacturing technologies. LCUSP will do this by (1) developing a copper alloy additive manufacturing design process, (2) developing a new Nickel Jacket additive manufacture/application process (3) additive manufacture of a 35K-class regenerative chamber/nozzle, (4) testing chamber and then chamber/nozzle system in a hot fire resistance test.

Integration with other projects/programs and partnerships

Liquid Propulsion System (LPS) Test Bed (being developed at MSFC with additive manufactured components such as injectors, LOx and H₂ Turbopumps plans to utilize the LCUSP Combustion Chamber or utilize the capability established under this project to fabricate a chamber. Test and Fabrication Data infused into Lander Technology Office methane thruster work. Follow-on regen Methane Engine Thrust Assembly for 4K lbf (META4) chamber design utilized SLM GRCo-84 process developed by LCUSP and incorporates LCUSP chamber mid-line weld design to enable required length. LCUSP printed faceplate provided strength, conductivity, and oxidation resistance needed for staged combustion testing in a much shorter time than it would have taken to procure stock and machine a traditionally fabricated GRCo faceplate, allowing MSFC to provide the first US data to USAF SMC. Industry partners are investigating possible partnerships with LCUSP for possible opportunities for fabrication of SLM combustion chambers to reduce cost of engine development.

Technology Infusion Plan:

PC, Propulsion, HEOMD, Potential use in manufacturing process of flight engines 2017. Military & Industry, SpaceX, Aerojet-Rocketdyne, Orbital-ATK, ULA, Blue Origin, ASRC Federal, numerous copper machine shops, suppliers, and electronics manufactories.

Key Personnel:

Project Manager: John Fikes

Project Element Manager: Eric Eberly

Lead Center: MSFC

Supporting Centers: LaRC & GRC

NASA NPR: 7120.8

Guided or Competed: Guided

Type of Technology: Push

Key Facts:

GCD Theme: LMAM, Lightweight Materials and Advanced Manufacturing

Execution Status: Year 3 of 3

Technology Start Date: April 2014

Technology End Date: September 2017

Technology TRL Start: 3

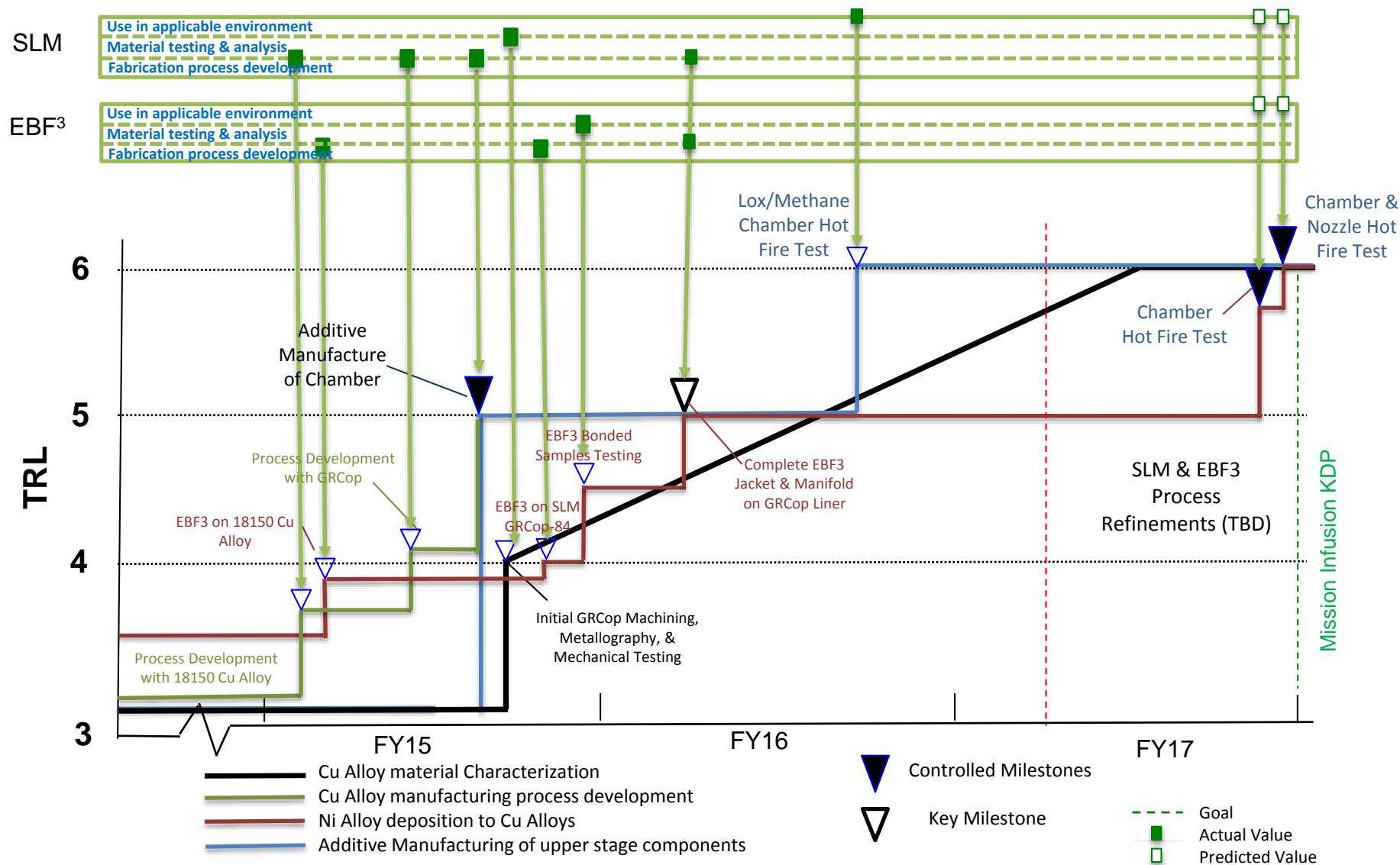
Technology TRL End: 6

Technology Current TRL: 4/5

Technology Lifecycle Phase: Implementation (Phase C/D)



LCUSP Component and System TRL Quarterly Assessment





Advanced Manufacturing Technology LCUSP Performance



- **Technology Advancements**
 - Selective Laser Melting (SLM) fabrication with GRCo-84 powder for rocket components (combustion chamber).
 - Electron Beam Free Form Fabrication (EBF3) application of In625 on SLM GRCo-84 (structural jacket for combustion chamber).
- **Technology advances mean**
 - Additive Manufacturing techniques to reduce cost and shorten schedule as well as produce intricate rocket propulsion components that may have been expensive or impossible to build with conventional techniques.
- **This is push technology**
 - Missions that require new propulsion systems can take advantage of this technology.

Key Performance Parameters

Performance Parameter	State of the Art	Threshold Value	Project Goal	Estimated Current Value
Process control of using Copper via SLM	SLM demonstrated with Inconel 718, Inconel 625, and Al 357, and CoCr by MSFC, but not with copper	Demonstrate parameter set that allows fabrication of monolithic structures to be used for mechanical properties and surface finish testing	Develop an optimized parameter set to maximize build speed, control surface finish, and maximize mechanical properties of SLM copper	GRCo SLM process yielding >99% dense parts with properties comparable to traditionally manufactured GRCo84 samples. External vendor has extended process to commercial application.
Copper alloy material characterization using SLM	Not established for copper	SLM'd GRCo-84 thermal conductivity at 90% of baseline extruded GRCo and remaining material properties at or greater than those of OFHC Copper	90% of baseline extruded GRCo-84 material properties	GRCo SLM process yielding >99% dense parts with properties comparable to traditionally manufactured GRCo84 samples.
Deposition of nickel alloy to SLM Copper	Demonstrated for pure nickel to pure copper, but not for nickel alloys to copper alloys	Deposition of nickel alloy to copper alloy that remains intact at the bond through a thermal cycle and with minimum defects	Deposition of nickel alloy onto copper alloy with a ductile transition zone and mechanical properties equivalent to cast annealed condition	Deposition process developed. Joint samples microscopy inspection and pull tests with no initial cracking show sufficient bond strength for design application. Further properties samples and process improvements to remove cracking being developed and tested.
Manufacture of AM upper stage engine components	SLM upper stage engine components demonstrated with Inconel 718, Inconel 625 by MSFC, but not with Copper (GRCo) chambers	Demonstrate build of subscale components or subassemblies with properties and geometry sufficient to be utilized in initial subscale testing	Demonstrate build of full-scale monolithic GRCo component parts with materials properties and geometric tolerance meeting key design features that allow successful tests with flight like conditions	Full scale H2 chamber go forward path developed. Successful methane tests of SLM printed chamber occurred 08/10/2016.



LCUSP Technical Accomplishments and Technical Challenges



Technical Accomplishments:

- **Held Design Checkpoint Review on 10/14/2016 to communicate recovery plan and design changes based on lessons learned.**
- **Manufacturing Readiness Review (MRR) completed for the Electron Beam Free Form Fabrication (EBF³) on 11/15/2016.**
 - Reverting back to process used on Unit 1.
 - Minor EBF³ adjustments based on Design of Experiments.
- **Unit 2.1 short chamber, 2.2 short chamber & Unit 3.0 Aft section GRCop-84 liners completed Select Laser Melting (SLM) production at MSFC.**
 - Unit 2.1 is at LaRC for EBF³ deposition.
 - Unit 2.2 is at MSFC for inspection after powder removal.
 - Unit 3.0 Aft is at HIP vendor.
- **Hot-fire milestones Change Request (CR) sent to GCD for review and approval.**
- **Mechanical Testing:** GRCOP-84 low cycle fatigue testing completed. In-625 cryogenic tensile testing completed.

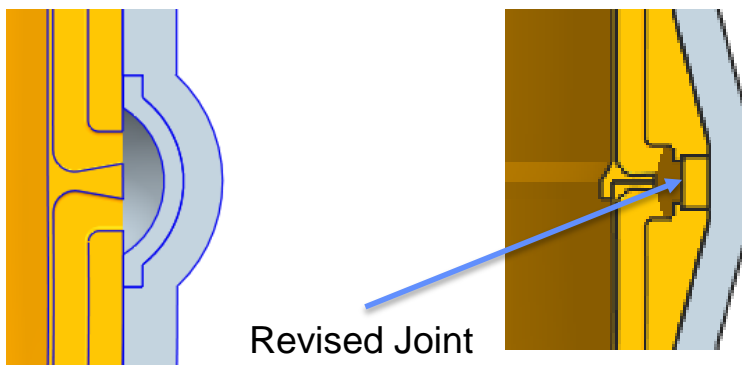


LCUSP Technical Accomplishments and Technical Challenges



Technical Challenges:

- **During Unit 2 Recovery, significant channel blockage was found in the Forward and Aft closeouts.**
 - New Recovery Plan Developed.
 - Change Request submitted to GCD.
- **The technical tall pole over the course of the project and for FY2017**
 - Inconel 625 jacket application using the Electron Beam Free Form Fabrication process.
 - Applying Structural Jacket over the intermediate manifold. The previous units used Inconel scaffolding. The new units will use GRCo-84 Closeout Ring.



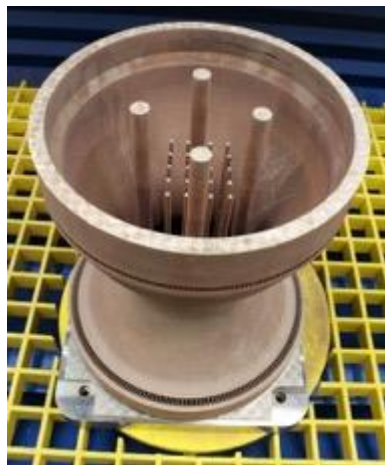
Revised Joint
Includes GRCo-84
Split Ring Closeout



Advanced Manufacturing Technology LCUSP Technical Accomplishments and Technical Challenges



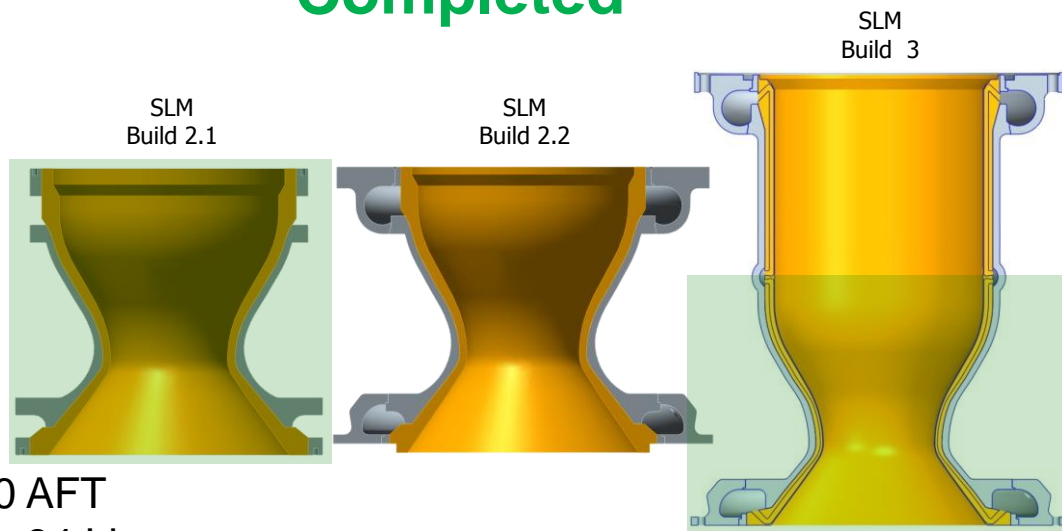
Unit 2.1 GRCo-84 Liner



Unit 2.2 GRCo-84 Liner



Select Laser Melting Productions Completed



Unit 3.0 AFT
GRCo-84 Liner



- Recovery Plan Includes
 - Unit 2.1 for EBF³ process validation
 - Unit 2.2 for Ebeam weld process trial and backup hot-fire unit
 - Unit 3.0 for primary hot-fire test article



LCUSP Plans for FY2017



GRCop-84/Inconel 625 Chambers

- Complete Unit 2.1 test chamber
 - EBF3 Inconel 625 onto GRCop-84 liner to verify process
 - Visual and CT scan inspection
 - Leak/pressure check
 - Destructive testing
- Complete Unit 2.2 chamber
 - EBF3 Inconel 625 onto GRCop-84 liner
 - Visual and CT scan inspection
 - Weld manifolds to Unit 2.2
 - Leak/pressure check
- Complete Unit 3.0 chamber
 - Weld Unit 3 halves together
 - EBF3 Inconel 625 onto GRCop-84 liner
 - Visual and CT scan inspection
 - Weld manifolds to Unit 3.0
 - Leak/pressure check

Chamber Hot Fire Testing (Unit 2.2 or Unit 3)

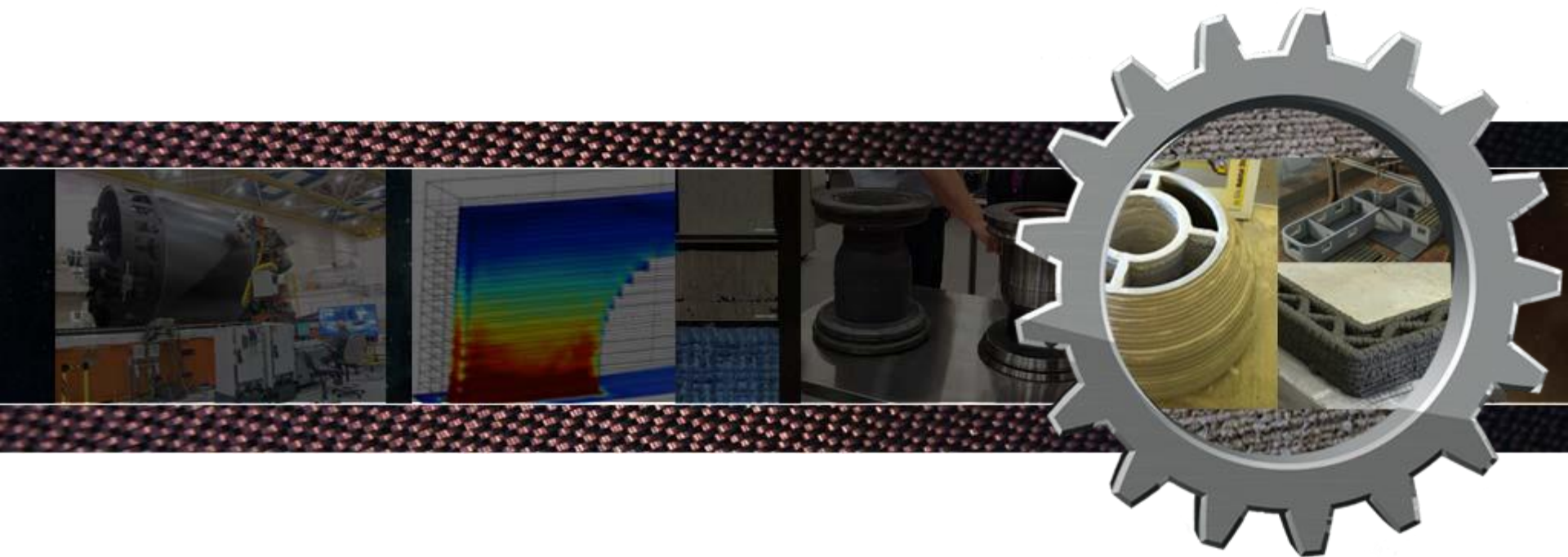
- Begin in late July
- Complete in August
- Complete integrated test in September

Materials Work

- Mechanical Testing
 - SLM Deposited GRCop-84 for Orientation & Size Study. Estimated completion in June 2017



Additive Construction with Mobile Emplacement





Advanced Manufacturing Technology ACME Project Overview



- Additive Construction with Mobile Emplacement (ACME) is 2D and 3D printing on a large (structure) scale using in-situ resources as construction materials to help enable on-location surface exploration.
- ACME is a joint effort between NASA/GCD and the U.S. Army Corps of Engineers (USACE).
- Applications are in the construction of infrastructure on terrestrial and planetary surfaces.

Integration with other projects/programs and partnerships

- Current partnership between MSFC, KSC, the USACE, Contour Crafting Corporation (CCC), and the Pacific International Space Center for Exploration Systems (PISCES).
- Collaboration with the JSC Hypervelocity Impact group.
- ACME personnel involved in the 3D Printed Habitat Centennial Challenge rules committee and serving as judges and subject matter experts (SME) for the various activities.
- 3D printing materials research involves members of industry (BASF, Premier Magnesia) and academia (Auburn University, Mississippi State, University of Mississippi).
- In-Situ Resource Utilization (ISRU) project integration & uses.

Technology Infusion Plan:

- Potential Customer: HEOMD, USACE and Industry (Caterpillar Inc.).
- Phased approach for maturation of hardware: ACME units intended to serve as prototypes for the USACE devices which will be used in domestic and international venues.
- ACME project advances in-situ resource utilization (ISRU), contour crafting, and zero launch mass construction materials development.
- Designed for use on planetary surfaces, can be deployed prior to human landing. Technology developed has terrestrial applications, and has large implications for the art of the possible in construction

Key Personnel:

Project Manager: John Fikes

Project Element Managers: John Fikes and Rob Mueller

Lead Center: Co-led by MSFC and KSC

Supporting Centers: None

NASA NPR: 7120.8

Guided or Competed: Guided

Type of Technology: Push for planetary ISRU, pull for terrestrial applications

Key Facts:

GCD Theme: LMAM

Execution Status: Year 3 of 3

Technology Start Date: 1/31/15

Technology End Date: 9/30/17

Technology TRL Start: 3

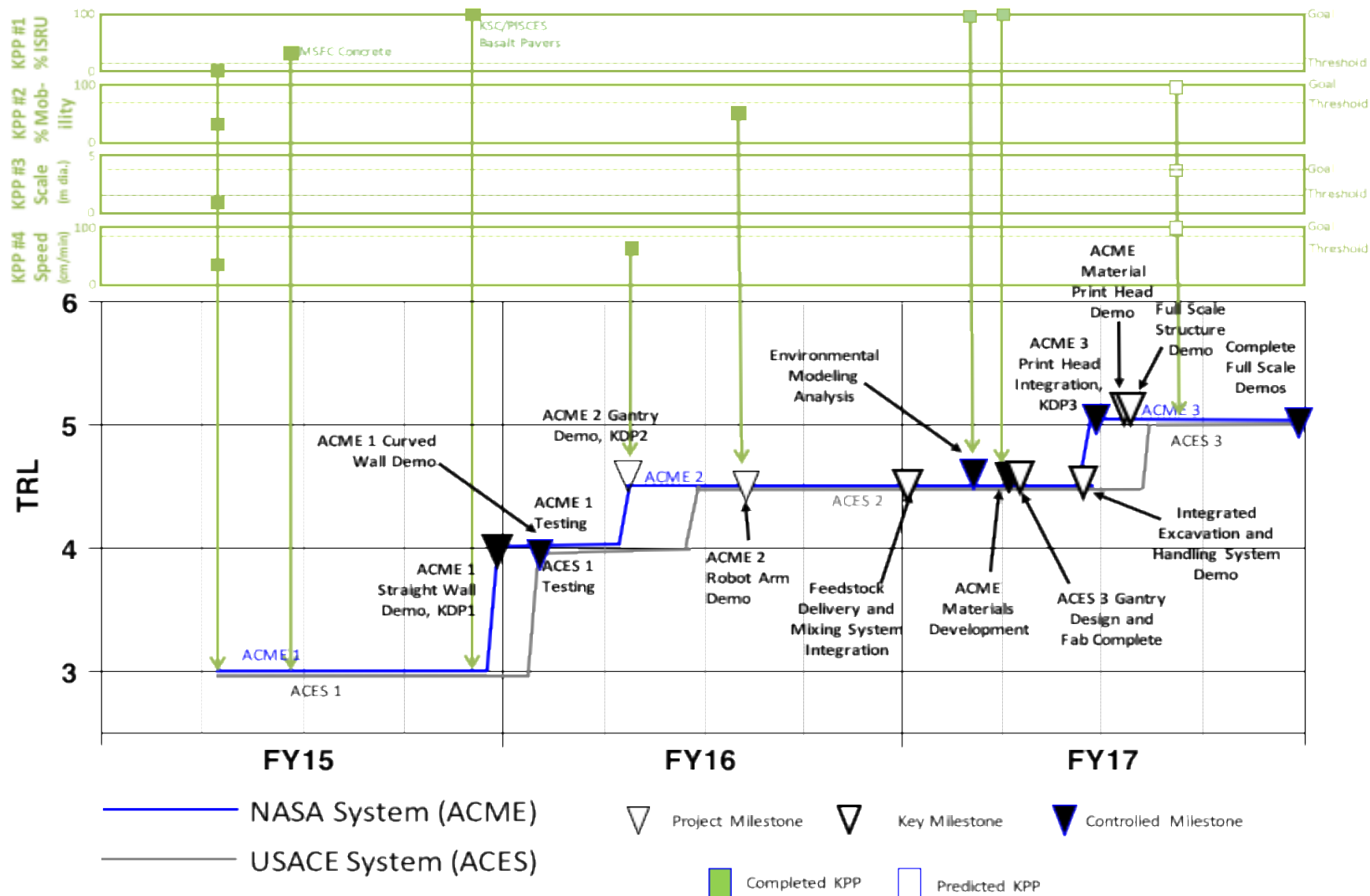
Technology TRL End: 5

Technology Current TRL: 4

Technology Lifecycle Phase: Formulation (Phase A)



ACME Component and System TRL/KPP Assessment





AMT ACME Performance



- **Technology Advancement**
 - Developed a continuous feed system for construction materials.
 - Integrated ACME 2 training nozzle into system.
- **Technology advance means**
 - Moving from batch processing to continuous feed; need further understanding of how feedstock viscosity, pump speed, and nozzle speed affect printing.
 - Ability to print structures continuously; no start/stop due to refilling with feedstock
- **Technology push and pull**
 - Impacts future planetary missions, in-situ resource utilization, and terrestrial applications (includes US Army and potentially industry)

Key Performance Parameters

Performance Parameter	State of the Art	Threshold Value	Project Goal	Estimated Current Value
KPP-1 Construction Material	Contour crafting with water-based concrete	Use in-situ regolith materials for manufacturing feedstock using imported binders	Use in-situ regolith materials for manufacturing feedstock using no imported feedstock materials	Demonstrated fabrication of construction material using regolith simulant and multiple binders (polymers, cements), as well as sintered regolith simulant. Performed compression tests and hypervelocity impact tests.
KPP-2 Emplacement	Subscale gantry mechanisms that are fixed in locations	Full scale gantry mechanisms in fixed locations	Mobile-ready print system	Demonstrated larger size gantry system. (ACES 2) Developed continuous feed capability. (ACME 2 and ACES 2) Design near complete for large scale mobile gantry system. (ACES 3) Gantry versus robot trade study complete. Report due 1/31/2017.
KPP-3 Construction Scale	Small concrete dome: ~1m high	In-situ regolith structure pad and curved wall; subscale optimized planetary structure	In-situ regolith structure pad and curved wall; full scale optimized planetary structure	Contour crafted martian simulant concrete straight and curved wall segments constructed. USACE additive printed guard shack (trials on 3/24, 5/5, 5/24 and final full size of 6'x8' on 7/6/16)
KPP-4 Print Head Construction Speed (1cm thick layers material)	30cm/minute	60cm/minute	100cm/minute	ACME 2 – 206 cm/minute ACES 2 – 508 cm/minute ACES 3 goal- 1270 cm/minute



ACME Technical Accomplishments and Technical Challenges



Technical Accomplishments:

- The ACES-2 DGFS was delivered to the United States Army Construction Engineering Research Laboratory (CERL) the first week of November 2016. Mods are currently taking place in preparation for a new motor installation for the weigh bin. A KSC software engineer is planning to be on-site at CERL the week of 2/6/2017 to assist with the install and testing.
- ACES-3 Liquid Delivery System Preliminary Design Review (PDR) was successfully completed at KSC on 11/29/2016. The ACES-3 Liquid Goods Delivery System (LGDS) Critical Design Review (CDR) is scheduled for 1/26/17 at KSC. Internal team review is complete.
- ACES-3 System Critical Design Review (CDR) was successfully completed on 12/8/2016.
- The energy chain concept was successfully tested on 12/5/2016, demonstrating the viability of this technique for hose management.
- Environmental Modeling analysis report that includes materials development work is complete (176 pages).

Technical Challenges:

- Meeting the U.S. Army Corp of Engineers (USACE) requirements with their current material (3/8th inch aggregate). ACME 2 runs were held on 11/10, 11/23, 11/28, 12/9. Work continues on characterizing the effects of material viscosity (standard mix and Martian simulant mix), pump speed, and the accumulator on concrete flow rate at the nozzle and overall nozzle performance.



Advanced Manufacturing Technology ACME Technical Accomplishments



The ACME team ran tests on 11/23/16, 11/28/16 and 12/9/16 with the Mars simulant mix to continue to understand the ACME-2 system variables.



The 12/9 test utilized the ACME-2 “training nozzle” and the ACME-2 accumulator. The purpose of the test was to demonstrate the capability to pump a batch of concrete with 17% of the stucco-based aggregate replaced with JSC Mars 1A regolith simulant through the modified ACME-2 system. Material flowed through both nozzle outlets. “Tearing” of the concrete during extrusion was witnessed. This phenomenon has only been seen while running the JSC Mars 1A regolith simulant through the ACME-2 “training nozzle”. The team is working to understand this phenomenon in order to better mitigate this issue.

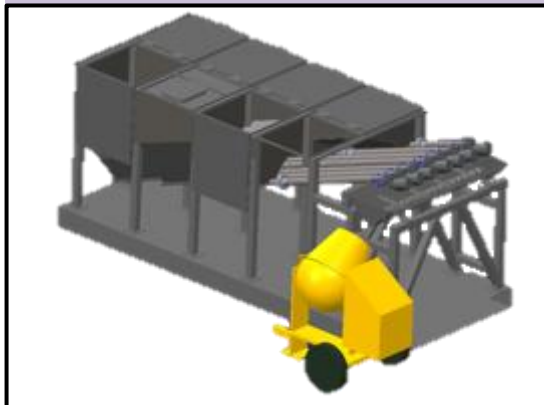




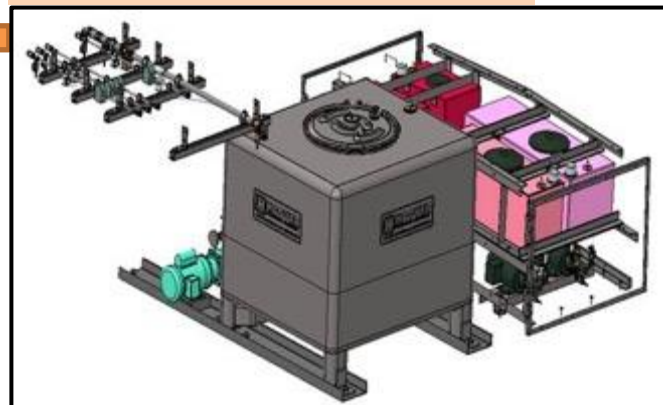
ACES 3 System



Dry Good Storage Subsystem



Liquid Storage Subsystem



Continuous Feedstock Mixing Delivery Subsystem (CFDMS)

Mixer

Pump

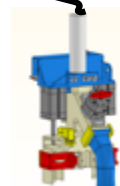
Compressor w/ Accumulator

Gantry

Nozzle



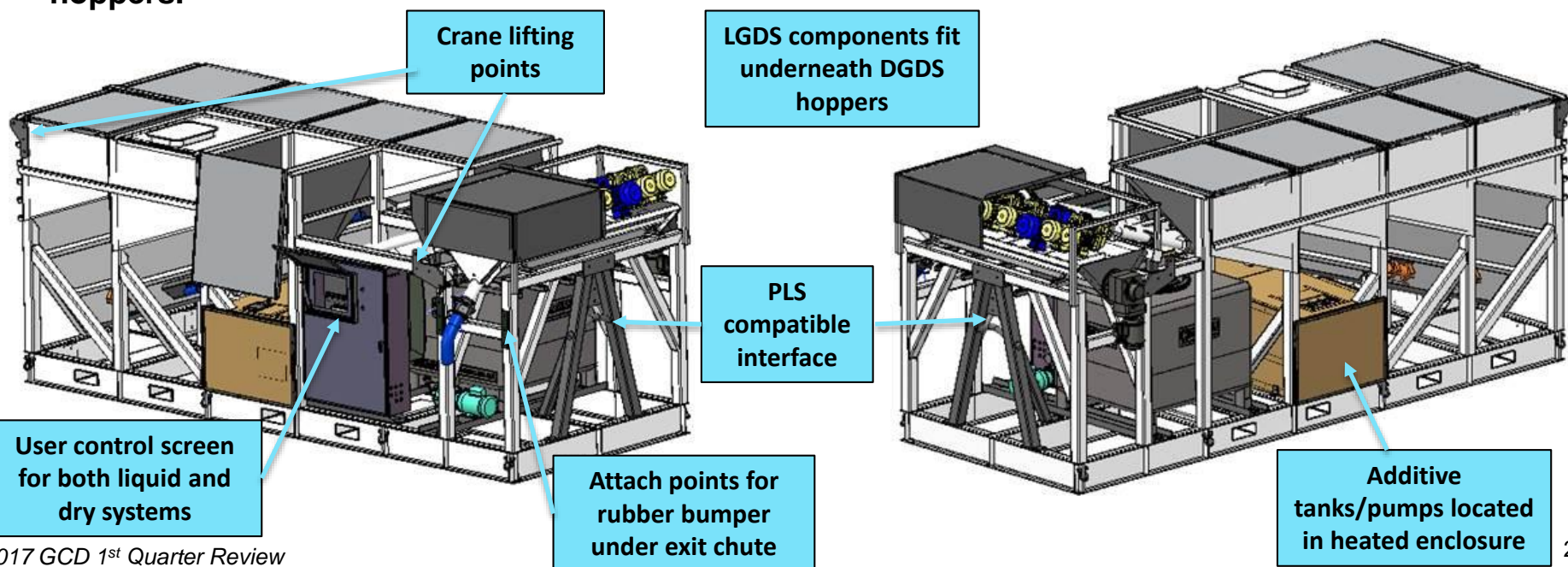
Hose





ACES-3 Dry Goods Delivery System

- **The ACES-2 DGFS was delivered to the United States Army Construction Engineering Research Laboratory (CERL) the first week of November 2016.**
 - Mods are currently taking place in preparation for a new motor installation for the weigh bin. A KSC software engineer is planned to be on-site at CERL the week of 2/6/17 to assist with the install and testing.
- **Several enhancements requested by the customer have been added to the design, including a bumper underneath the weigh bin exit chute, crane lifting points, and a Palletized Loading System (PLS) compatible interface on the structure.**
- **The bulk of the Liquid Goods Delivery System (LGDS) will be colocated underneath the dry good hoppers.**



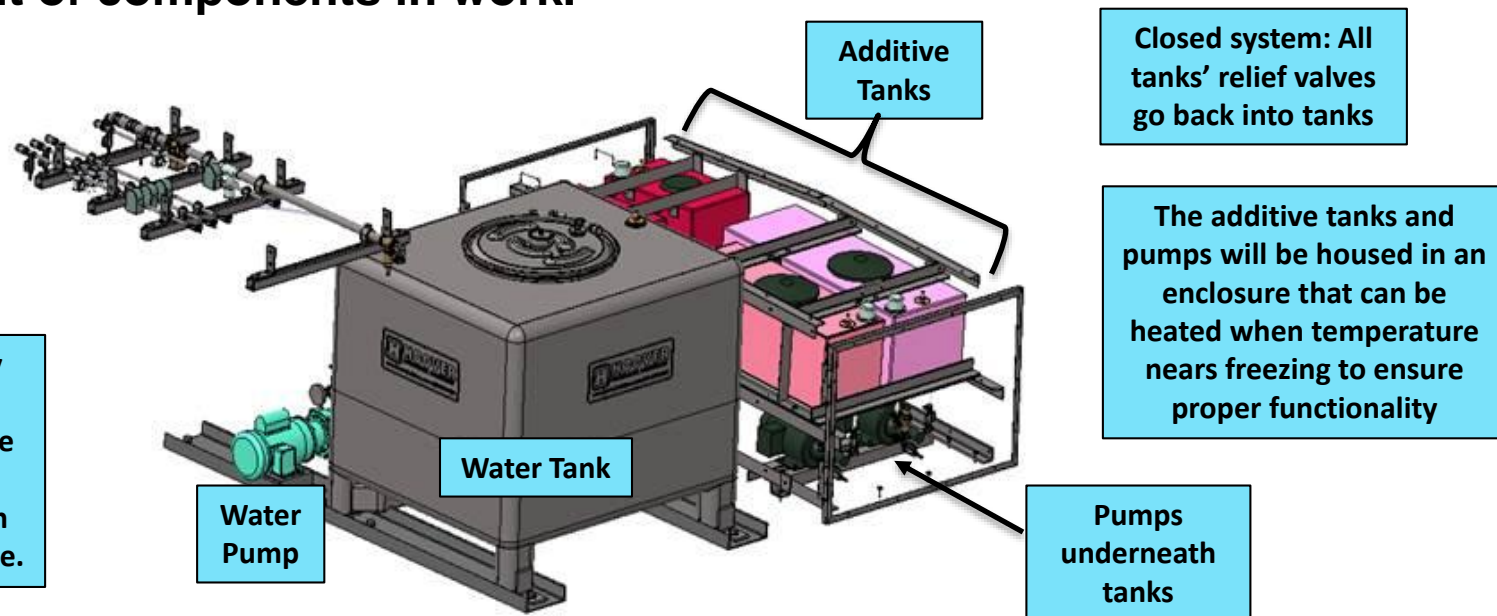


ACME Technical Accomplishments and Technical Challenges



ACES-3 Liquid Goods Delivery System

- ACES-3 Liquid Goods Delivery System Preliminary Design Review (PDR) with Chief Engineers completed at KSC on 11/29/16.
- ACES-3 Liquid Goods Delivery System Critical Design Review (CDR) with Chief Engineers scheduled at KSC for 1/26/17.
- Modeling of Liquid Goods Delivery System complete, drawings and analysis to be completed by 1/24/17.
- Procurement of components in work.



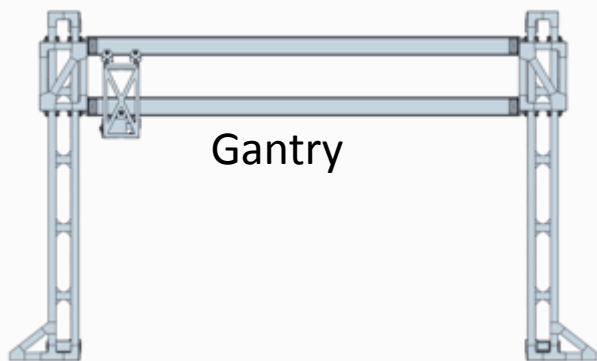
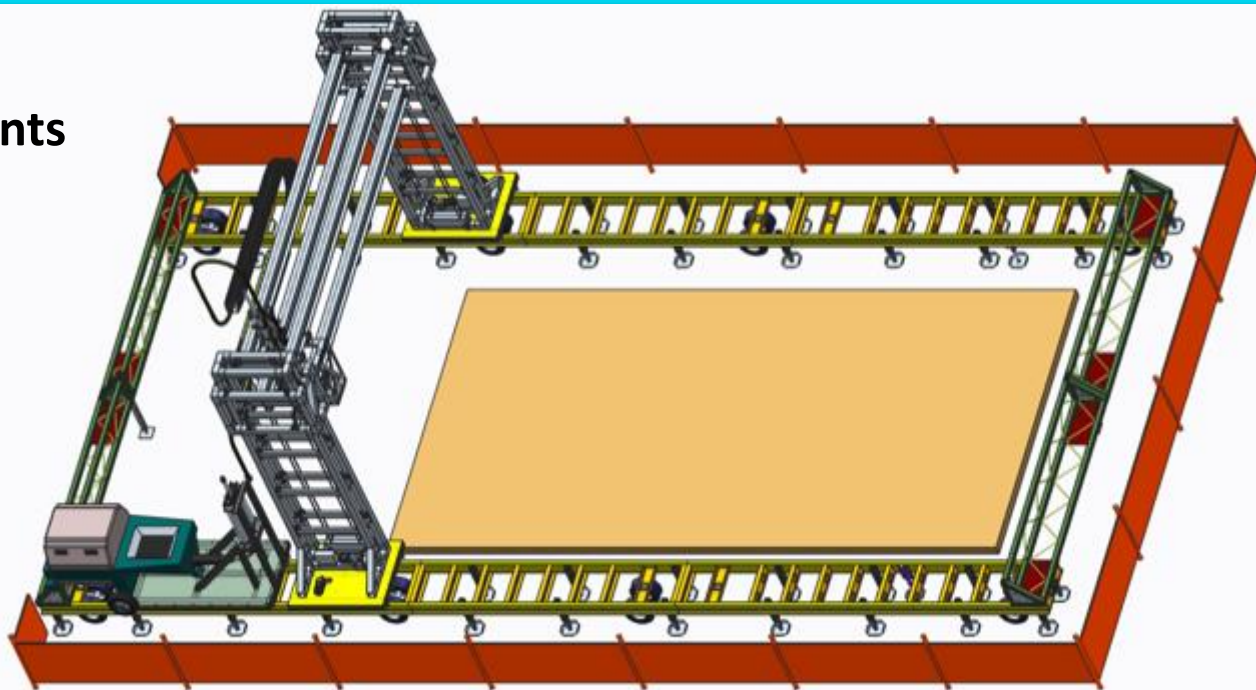


ACES 3 Design



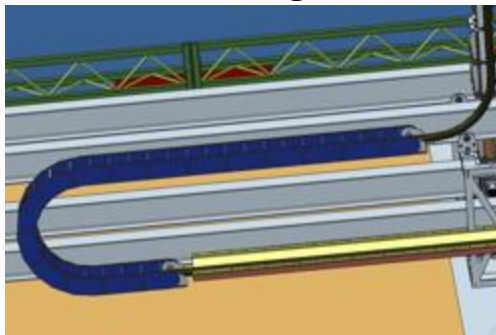
ACES 3 Major Components

Accumulator
Pump Trolley

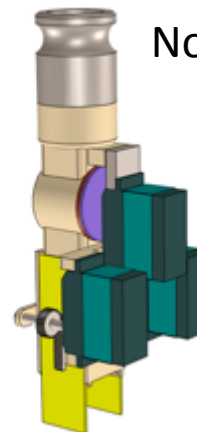


Gantry

Hose Management



Nozzle

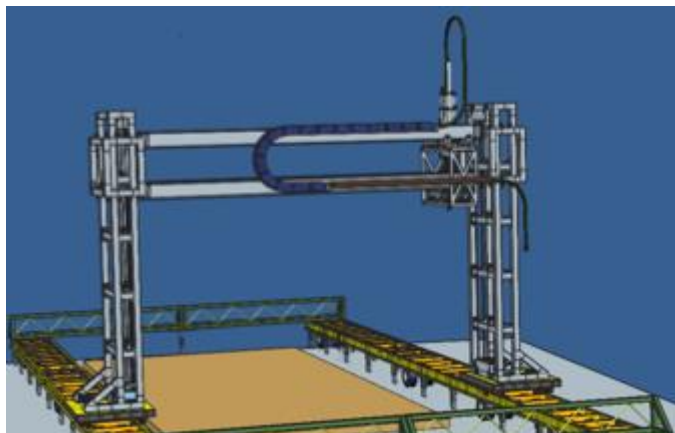


Electrical &
Software





Advanced Manufacturing Technology ACME Technical Accomplishments



Tests were performed on 12/5/2016 to demonstrate the use of an energy chain to assist with hose management. As part of the tests, a 2" hose was filled with wet sand and was bent, extracted, and inserted into the energy chain.





Additive Construction with Mobile Emplacement

Technical Accomplishment:

ACME Materials Development Complete



Milestone: Select a construction material that can be produced on Mars and used in additive construction technology.

Completed December 29, 2016

Deliverable: Notification of the use of a polyethylene-regolith mixture, as well as compression and flexure test results, of the proposed material. This material will be pursued for the future print head development milestone.

PROBLEM: The use of in-situ resources is necessary to reduce the cost of missions. Planetary construction material development is still in its infancy. Additive construction on planetary surfaces requires a material that can be produced in-situ, but still work with additive construction technology.

Objective: Determine a material that can be produced in-situ and serve as a planetary construction material to be used in additive construction.

Approach: Use current knowledge of available surface and atmosphere resources and binders that can be produced from those resources to identify a combination that can be produced 100% in-situ on Mars. Optimize the mixture for additive construction.

Results: Selection of a polyethylene (produced from the atmosphere of Mars) regolith mixture. The mixture requires heating and mixing for extrusion and use in additive construction; a print head is in development.

2017 GCD 1st Quarter Review



Standard 2-inch cube compression test specimens with varying ratios of polyethylene to regolith.



ACME Milestone Completion: Environmental Modeling Analysis



Objective:

Record work completed to date in the study of candidate planetary construction materials specific to the environment of use: Mars atmosphere tests, compression load tests, hypervelocity impact tests, and radiation protection modeling.

Milestone completed on 12/30/16. This is a living document updated monthly

Key Accomplishment/ Deliverable/Milestone:

- Summarized experiments to date involving curing of planetary construction materials in a Mars environment (CO_2 gas and ~ 7 Torr pressure).
- Summarized compression testing data used to optimize the strength of material mixtures.
- Summarized hypervelocity impact test results applicable to both NASA and the Army Corps.
- Summarized radiation modeling parameters and modeling completed to date on single point spherical (dome) geometry for both Galactic Cosmic Rays and Solar Particle Events. Future work includes geometries more likely to be built on planetary surfaces and additional materials.



Mars simulant and Ordinary Portland Cement cured in a CO_2 atmosphere at ~ 7 Torr (left), EMA report cover (right).

Significance:

- Established a living document to record analyses completed on planetary construction materials relative to their environment of use.
- Records planetary construction materials development, strengthening of these materials through experimentation, resistance of the material to hypervelocity impact, and the potential for radiation protection for future Mars habitats.



ACME Plans for FY2017



- **FY17 Plans**

- Completion of mobility trade study report.
- Deliver third generation ACME and ACES hardware. (Nozzle, accumulator, wet goods subsystem, gantry)
- Fabricate a representative planetary structure. (NASA)
- Fabricate an expeditionary structure. (USACE)

- **FY17 Threats**

- Deliver third generation ACES hardware by April 1, 2017.



Summary and Significant Challenges



Project Summary Performance

Project	Summary Performance				Rationale
	Technical	Cost	Schedule	Programmatic	
Quarter 1					<p>Technical- AMT is yellow overall due to challenges utilizing the EBF³ process to add an inconel structural jacket to the GRCop-84 liner without producing cracks. (LCUSP) & due to on-going challenges to meet the U.S. Army Corp of Engineers (USACE) requirements with their current material (3/8th inch aggregate). (ACME)</p> <p>Cost- AMT is yellow overall due to the new recovery plan requiring more resources at LaRC. (LCUSP)</p> <p>Schedule- AMT is yellow overall due to technical challenges resulting in lack of schedule reserves for project deliverables. (LCUSP & ACME)</p>
Quarter 2					
Quarter 3					
Quarter 4					

Significant Challenges

LCUSP

- Understanding the failure modes and root cause of the EBF³ inconel to copper interface is required to successfully demonstrate objectives of the LCUSP project. Team working to understand process variability.

ACME

- Delivering the ACES 3 system to the USACE that meets their requirements by April 1, 2017.



Back Up Charts

<These charts feed Quarterly Reporting. All charts are required. >



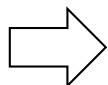
AMT/ LCUSP

EBF3 Weld Technology of Inconel 625 on GRCo-84



Risk ID #

1



Trend

HIGH

Criticality

Current L/C

5x4

Affinity Group

T, C, Sc

Planned Closure

9/2016

Open Date

12/17/2014

Risk Statement:

Given that this project involves developing new processing parameters in an effort to deposit a Ni-alloy onto the GRCo liner, there is the possibility that the combined jacket/liner part does not meet the structural or geometric requirements resulting in impacts to project schedule and technical objectives.

Context: EBF3 application of Inconel on other material been used before, but the EBF3 application of Inconel on GRCo-84 has never been done previously.

Status: The 2.5" plugs (pre and post HIP) were examined on Unit 1 and inspection thru electron microscope showed good results to proceed. The interface samples have been fabricated and machined and will be tested in May. A bigger issue has arisen with leaks identified in Unit 2. The leaks were found **post HIP** at the ends of the chamber and is suspected to have occurred during tooling extraction or HIP. Fault analysis and Unit 2 fix are being investigated at this time. CT scans show majority of the EBF3 application was done well, the end effects/crack can be mitigated and Unit 1 forward section was successful and had no leakage. The risk has been realized and **likelihood has changed from 2 to 5 and the schedule has been impacted.**

Approach: Mitigate

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C1.
1. EBF3 deposition parameters are being developed that do not exhibit hot cracking by modifying the total thermal input (limiting the temperature of the Cu will lower the expansion due to CTE) when depositing In625 on to a pure Cu flat plate.				12/2014	3/4
2. Experiments are planned on a C18150 Chamber Simulator to assess the effect of higher strength and hoop stresses in a cylindrical geometry		7/2015		skipped	2/4
3. Prior to EBF3 deposition of the In625 structural jacket on the actual test article, experiments are planned on GRCo subcomponent sections built with internal passages to measure the impact of EBF3 deposition		7/2015		10/2015	2/4
4. Metallurgical analyses are planned to examine the microstructures and precipitate morphologies at the interface between the GRCo and In625		On going as samples are made		12/2015	2/4
5. Examine 2.5" plugs (pre and post HIP) to understand the GRCo/Inconel Interface. Also tensile test of material interface and subsequent analysis show structural integrity		Interface looked very good		5/2016	1/4
6. The Hot Fire Test article passes Proof Pressure Test and Cold Flow Test				6/2016	close



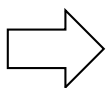
AMT/ LCUSP

GRCop-84 and Inconel625 Interface flaws



Risk ID

8



Trend

Med

Criticality

Current L/C

1x5

Affinity Group

Technical

Planned Closure

May 2016

Open Date

Dec. 2015

Risk Statement:

Given observations of flaws produced by the fabrication process as it has been developed to date and the lack of characterization for the critical flaw size and the lack of developed measurement techniques specific to this new manufacturing technique and geometry there exists the possibility of catastrophic failure of the part and loss of project objectives.

Approach: Mitigate

Context: Advancement of TRL from 3 to 6 as well as current GCD philosophy of higher risk with potential high gain opportunity is being utilized for this project. This is not flight hardware and there is minimal risk to the test stand. "Good Enough" instead of "Perfect" approach is being utilized control schedule. With schedule constraints and given that the flaws were recently observed in the samples, the quality control of EBF3 of Inconel on GRCop for material integrity thru out will be difficult. Perfection of method with multiple statistical samples in various configurations are not possible within schedule or cost constraints.

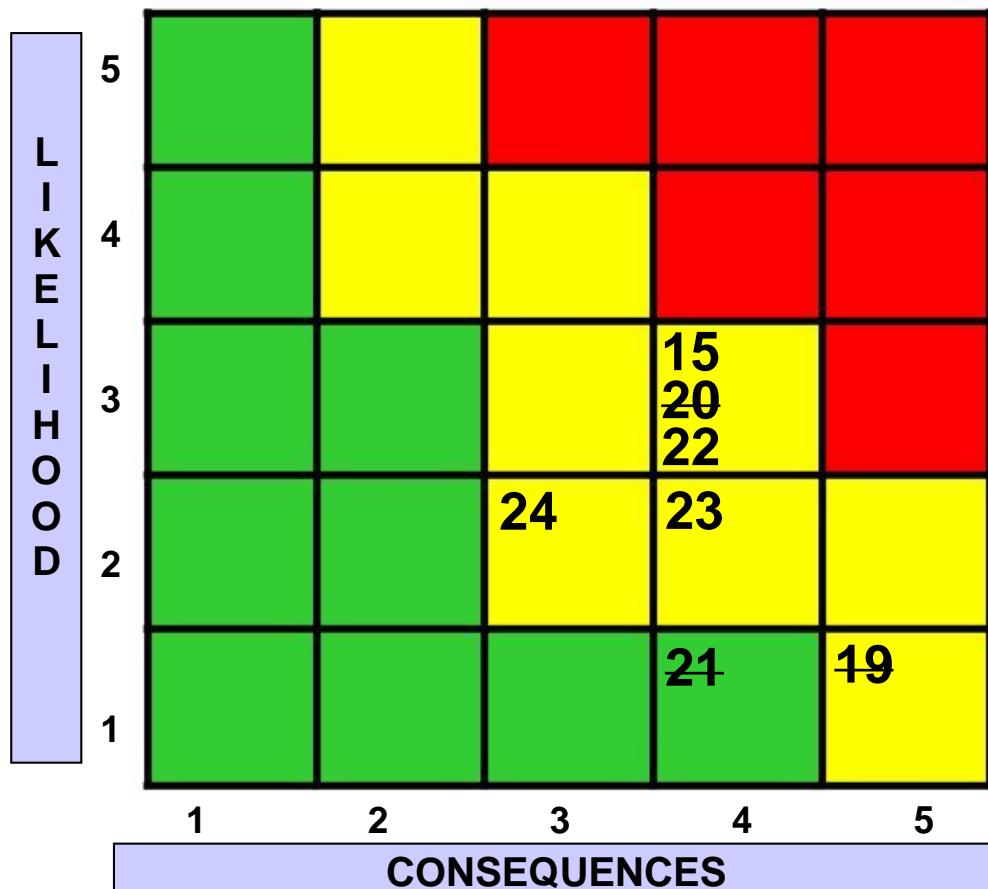
Status

Testing and Analysis of samples are part of the current process for learning good fabrication process. An additional HIP after application of the Inconel625 Jacket has been incorporated to close up cracks or gaps or flaws in material interface. Sample Trials on 3" section has been analyzed and evaluated. CT scans look good except at fore and aft ends and with the evaluation of the plugs from unit 1 looking good, the likelihood was reduced from 2 to 1. The end effect cracks are addressed in Risk 1

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Initial					3x5
2. Additional thickness incorporation into Inconel625 Jacket and HIP entire Chamber after Jacket application				10/2015	2x5
3. Material Interface Inspection & Analysis at sample points. Also material strength testing.		12/2015		11/2015	2x5
4. Pathfinder 1 st Unit will go thru the same application process for identifying improvements as well as for analysis and testing. Plugs from 1 st Unit will be inspected and additional interface samples made to improve analysis.		Done 3/2016		4/2016	1x5
5. NDE of Chamber (X-ray or CT scans)		Done 5/16		5/2016	1x5
6. First order analysis of key geometries with representative flaws for minimum crack length allowable for crack propagation and chamber failure will be performed as test data is available.				5/2016	1x5
7. Proof Pressure check and Cold Flow prior to hot fire				9/2016	1x5



ACME Risk Assessment



Risk ID	Risk Definition	Approach	Est. Closure Date
15	Facility Operating Space	Mitigate	1/25/2017
19	Safety Keep Out Zones	Mitigate	01/18/2017
20	Integration, Testing Space (Weather Impacts)	Mitigate	1/11/2017
21	Hose Management	Mitigate	12/15/2016
22	Logistics for Fabrication, Assembly, Integration	Mitigate	1/31/2017
23	Nozzle Development and Test	Mitigate	01/31/2017
24	Accumulator Development and Test	Mitigate	02/14/2017

	Total			0-30 days			30 - 60 Days			60 - 90 Days			> 90 Days		
R, Y, G	3	13	8	2	1*	0	1	0	2	1	1	2	1	11	4
Open	18			3			3			4			10		
Closed	13			5 X 5 is per System Engineering Handbook											

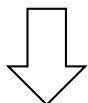
5 X 5 is per System Engineering Handbook NASA/SP-2007-6105



Facility Operating Space

15

Trend



Criticality

Med

Current L/C

3x4

Affinity Group

Schedule,
Performance

Planned Closure

01/25/2017

Open Date

02/16/2016

Risk Statement

Given that the ACME team must relocate all resources (i.e. hardware) to another facility and an appropriate facility is not identified, resulting in not having the needed facility space to build and operate the ACME system, there is a possibility that the ACME team will not be able to operate the system, resulting in not meeting GCD and USACE milestones.

Approach: Mitigate

Context: ACME was allowed to operate in an older machine shop building knowing that at some point the “owner” of the building would need the building again. The owner of the machine shop building has started updating the building and will need the building around mid-April/ early-March. 2016 This risk affects meeting the milestones associated with ACME-3. Facility needs water, drainage to outside, storage space, electricity and a 80’x80’ foot print.

Status 01/12/2017 The LxC was updated from a 5x4 to a 3x4 resulting in a decreasing trend. Updated closure date from 01/18/2017 to 01/25/2017. A facility space has been located on-site (building 4757A). Building 4757A has some items that will need to be moved out before it is usable . There are issues that need to be addressed. Additional 110V power needs to be supplied, 3 -phase power needs to be available, additional lighting inside needs to be added. Solutions for drainage, water supply, and 3-phase power need to be developed as well.

12/21/2016 There are further issues with facilities locating a space and providing information about procuring a tent. The need for a usable facility is 01/18/2017. After this date, schedule delays are very likely to occur (one-for-one).

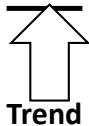
Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Evaluate off-site options (Dynerics).					
2. Request assistance from MSFC management to find an outside space and use a tent or some other temporary shelter with a generator and water supply.					
3. Develop an alternate plan to store procured hardware until assembly is needed.					



ACES-3 Fabrication, Assembly, & Integration Logistics



22



Med

Criticality

Current L/C
3x4

Affinity Group
Schedule, Cost

Planned Closure
01/31/2017

Open Date
10/27/2016

Risk Statement

Given that the design of the hardware and software for ACES-3 includes fabrication, assembly, and control of large structural pieces, there is a possibility that certain logistics could be overlooked or underestimated, resulting in schedule loss and increased technical costs due to not planning the right resources prior to fabrication, assembly, and integration.

Approach: Mitigate

Context ACES-3 system is a large system (at least 30'x20'x15') and will require the use of equipment for assembly. Machine shops need to be identified and confirmed that they can accommodate fabrication requests. Any transportation needs should be identified. Secondary equipment needed for the assembly and integration need to be identified and confirmed or bought.

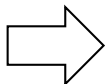
Status 01/12//2017 Updated LxC from 1x4 to 3x4 resulting in an increasing trend. The closure date was updated from 01/18/2017 to 01/31/2017. The new facility space does not have water. The project will need to supply water tanks (approx. 500 gallons per tank) and a pump. At least one tank will be needed to hold clean water and at least three will be needed to hold used water. Used water cannot be drained on-site. Used water tanks will need to be hauled away by the heavy lift organization. Heavy lift could be prioritized to assist with SLS and cause a delay with hauling away the water tanks. Used water tanks will be cleaned and brought back. Three-phase power for operation of the ACES-3 system will need to be brought in. USACE is providing an M100 power distribution panel but the project will need to locate a power source. These issues could impact cost and schedule. The project would like to begin fabrication based on preliminary drawings. EV is suggesting to wait until issued drawings are released before any fabrication. This could greatly impact schedule.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Develop an AI&T plan to identify resources needed at critical times.				12/06/2016	



ACES-3 Nozzle Development and Test

23



Trend

Med

Criticality

Current L/C
2x4

Affinity Group
Technical

Planned Closure
01/31/2017

Open Date
11/17/2016

Risk Statement

Given that the Contour Crafting nozzle has proven to be difficult on both ACES-2 and ACME-2, there is a possibility that a poorly-designed nozzle for ACES-3 can result in not having the ability to sculpt the concrete and stop flow of the concrete when needed.

Approach: Mitigate

Context

Neither the ACME-2 or ACES-2 nozzles have worked as intended. There have been issues with concrete only flowing out one side of the nozzle, poor bead width consistency, the cutters not extending correctly to stop flow, and parts easily broken. Proper testing to identify the causes of these issues is needed.

Status 01/12/2017 The planned closure date was updated from 01/18/2017 to 01/31/2017. CCC has fabricated a plastic prototype of the ACES-3 nozzle. CCC provided analytical models for the team to review. The team has provided feedback to CCC. The current design and fabrication method for the ACES-3 nozzle requires additive manufacturing (AM). Using AM may require the material of the nozzle to be changed to better suit the fabrication process. A material change will result in a requirements change, but this is a minimal impact. Planned testing using the ACES-2 nozzle that would generate potential design data may be impacted by available resources (e.g. workforce).

12/05/2016 Updated closure date from 12/05/2016 to 01/18/2017. There were issues with the material mix on 12/02/2016, so the run was cancelled and has been rescheduled for 12/09/2016.

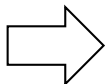
Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Develop a fault tree analysis for ACME-2 nozzle to identify potential variables.		11/17/2017			
2. Test potential design solutions.					
3. Pending results, incorporate nozzle design solutions.					



ACES-3 Accumulator Development and Test



24



Trend

Med

Criticality

Current L/C
2x3

Affinity Group
Technical

Planned Closure
02/14/2017

Open Date
11/17/2016

Risk Statement

Given that the accumulator has proven to be difficult on ACES-2, there is a possibility that a poorly-designed accumulator for ACES-3 can result in not having the ability to control and stop flow of the concrete.

Approach: Mitigate

Context

There are unknowns associated with the ACES-3 accumulator since there has been limited testing of the ACES-2 accumulator. The accumulator for ACME-2 does work as intended. The materials used for ACES-2 and ACME-2 are different, so it is unknown if a one-for-one comparison can be assumed.

Status 01/12/2017 Planned testing using the ACES-2 accumulator that would generate potential design data may be impacted by available resources (e.g. workforce). The same resources required for the fabrication and assembly of ACES-3 are the same resources required to operate the ACES-2 system. There is no testing currently planned.

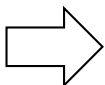
12/21/2016 The ACES-2 accumulator was delivered to MSFC on 12/20/2016 for testing.

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Incorporate design changes to accommodate higher pressures.				12/08/2016	
2. Modify the current ACES-2 accumulator with the current Acas-3 design.				01/18/2017	
3. Test the ACES-2 accumulator with the ACES-2 nozzle on the ACME-2 system.				01/31/2017	



ACES-3 Safety “Keep-Out zones”

19



Trend

Med

Criticality

Current L/C
1x5

Affinity Group
Technical

Planned Closure
1/18/2017

Open Date
10/27/2016

Risk Statement

Given that the ACES-3 mobility system will utilize several high voltage motors and power supplies designed to move large masses very rapidly, and that there is a tendency for personnel on the project to work within the construction volume even during construction, there is a possibility of personnel being struck by rapidly moving hardware or being electrically shocked, resulting in significant injury or death.

Approach: Mitigate

CLOSED 12JAN2017

Context

Historically to date, there have been many instances where both ACME and ACES personnel have worked within the construction volume while the hardware was operating.

Status 01/12/2017 **CLOSED** A design to inhibit people from entering the work area while the ACES-3 system is being used was addressed during the CDR on 12/08/2016. The risks of entering the work area will also be called out in the operation manual.

12/01/2016 Updated the closure date from 12/15/2016 to 01/18/2017. Separated out the mitigation step 2 into design and fabrication steps. Completion dates for those reflect what is in the integrated schedule. The team is awaiting OSHA and other safety requirements to incorporate into a revision of the requirements.

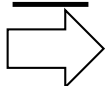
Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1. Modify the requirements to include safety keep-out zones.					
2a. Design physical barriers (tied to a power “kill” switch to keep people out.		10/27/2016		12/15/2016	
2b. Fabricate physical barriers (tied to a power “kill” switch to keep people out.		12/15/2017		02/14/2017	
3. Modify all existing or future operating procedures to define this new protocol.		10/27/2016		02/14/2017	



ACES-3 Integration/Test Location (Weather Impacts)



20



Trend

Med

Criticality

Current L/C
3x4

Affinity Group
Schedule

Planned Closure
1/11/2017

Open Date
10/27/2016

Risk Statement

Given that the ACES-3 project is on a very tight schedule and that hardware integration is scheduled to occur in the Dec-Feb timeframe and that all locations identified by MSFC for integration and test are outdoors and that the average historical % of days below freezing for Dec-Jan-Feb is 20-27-21% and average days with measurable precipitation is 40-45-45%, there is a possibility of between 20 and 45% of workdays being unworkable due to weather, resulting in significant schedule delays.

CLOSED 12JAN2017

Approach: Mitigate

Context The assembly/integration area required for ACES-3 is approximately 50' x 30', 15-20' high. MSFC has been looking for possible indoor locations on-site, with no luck. Several outdoor locations have been identified and are under evaluation. This is not a requirement for operation, but a requirement for assembly.

Status 01/12/2017 **CLOSED** An enclosed facility location has been found and secured.

12/01/2016 Assessing another building, but have started the process to acquire a tent if needed.

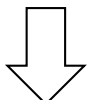
11/17/2016 Added additional context "this is not a requirement for operation, but a requirement for assembly."

Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1 Continue to look for indoor locations, preferably close to 4739.		10/27/2016			1x4
2 Evaluate options of renting or buying a tent and other environmental enclosure elements to cover the structure during assembly/test					1x4



ACES-3 Hose Management

21



Trend

Low

Criticality

Current L/C

1x4

Affinity Group

Technical

Planned Closure

01/10/2017

Open Date

10/27/2016

Risk Statement

Given that concrete hose management has proven to be difficult on both ACES-2 and ACME-2, there is a possibility that improper or poorly-designed hose management techniques for ACES-3 can result in clogging, binding, or difficulty in extraction/removal of hoses for cleaning.

CLOSED 12JAN2017

Approach: Mitigate

Context

When a two-inch diameter hose is filled with concrete, the weight of the hose is significant. The extra weight makes it more difficult to manage the movement of the hose. This can affect the printing process because of complications like clogging or binding. Having a design that allows for easy extraction and removal of the hose for cleaning purposes is ideal. The CDR for the gantry system that encompasses the hose design will occur in early December.

Status 01/12/2017 **CLOSED** Testing was performed using the energy chain that will be used for hose management. The hose movement will meet the project requirements. Testing of the energy chain with hose to meet cleaning requirements was observed with no expected complications.

12/21/2016 Updated closure date from 12/15/2016 to 01/10/2017. Awaiting comments from the ACES-3 Critical Design Review board before closing to address any concerns of the board.

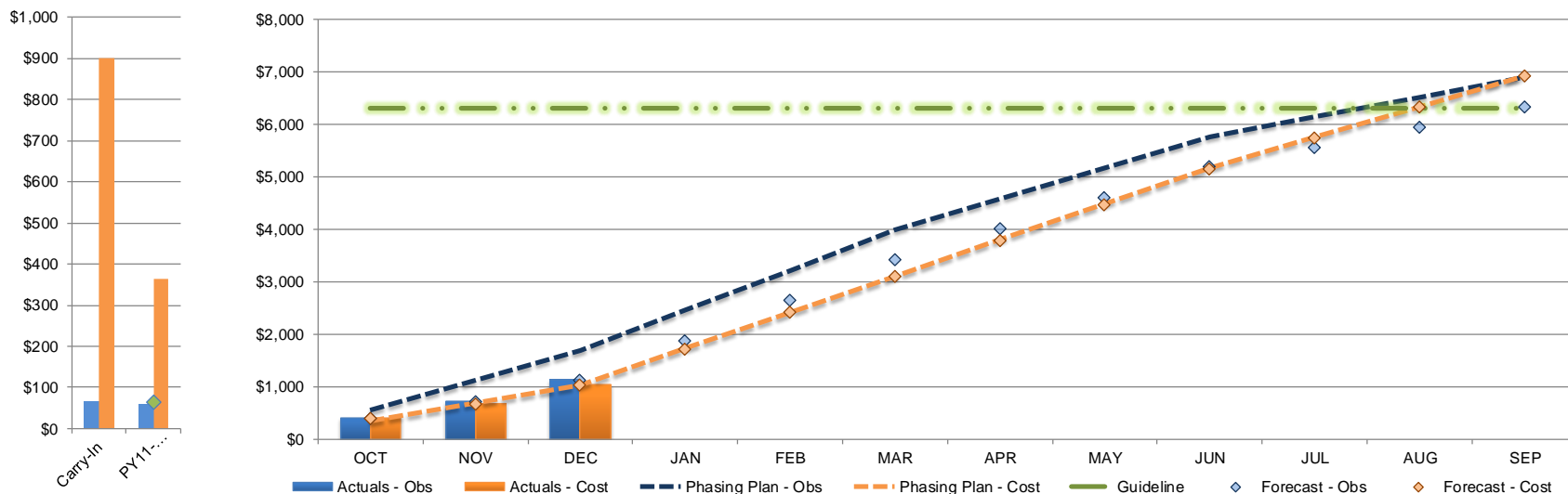
Mitigation Steps	Dollars to implement	Trigger/ Start date	Schedule UID	Completion Date	Resulting L/C
1 Test hose configuration concepts in the lab.					



Resources: Total Obligations and Cost



FY 2017 Financial Status



	Cum (\$K)	Carry-In	PY11-16 Funds	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Carry Out
Obs	Guideline		65.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	6,314.0	
	Phasing Plan (RLP)			560.7	1,121.3	1,682.0	2,453.7	3,225.4	3,997.1	4,585.3	5,173.6	5,761.9	6,139.8	6,517.8	6,895.8	(576.3)
	Actuals	65.0	59.6	406.1	731.0	1,120.7										
	Forecast			406.1	731.0	1,120.7	1,892.4	2,664.1	3,435.8	4,024.0	4,612.3	5,200.6	5,578.6	5,956.5	6,334.5	(15.0)
Cost	Phasing Plan (RLP)			345.2	690.3	1,035.5	1,727.0	2,418.5	3,110.0	3,795.1	4,480.2	5,165.3	5,754.2	6,343.1	6,932.1	555.0
	Actuals	901.3	364.1	394.3	685.9	1,037.9										
	Forecast			394.3	685.9	1,037.9	1,729.4	2,421.0	3,112.5	3,797.6	4,482.7	5,167.7	5,756.7	6,345.6	6,934.5	(8.7)

Note: Carry-In is the unobligated/uncosted portion of PY11-16 funding end of FY16

	YTD Status	Explanation required for YTD Variance in excess of 5% from Phasing Plan (shaded red)
'17 Obs	Phasing \$ 1,682	Currently operating under CR thru April 2017. Contractual commitments/obligations are on-going and are expected to start catching up during the 2 nd quarter of FY2017. Project activities on-going and there have been no impact to project milestones.
	Actuals \$ 1,121	
	Variance \$ (561)	
'17 Cost	Phasing \$ 1,035	
	Actuals \$ 1,038	
	Variance \$ 2	



Excel File: STMD and GCD Data Request



- **Milestone Completion and Burndown**
- **Technology Transfer or Infusion**
- **EPO: Activities, Conferences, and Students**
- **Economic Development**
- **Post Excel File to the following link on NX:**
<https://nx.larc.nasa.gov/dsweb/View/Collection-95546>

Use Excel file sent with the template and located on NX



Low Cost Upper Stage-Class Propulsion (LCUSP) Penta



PROBLEM / NEED BEING ADDRESSED

Current rocket propulsion manufacturing techniques are costly and have lengthy development times

PROJECT DESCRIPTION/APPROACH

- Develop materials properties and characterization for SLM manufactured GRCo
- Develop and optimize SLM manufacturing process for a full component GRCo chamber and nozzle
- Develop and optimize the Electron Beam Freeform Fabrication (EBF3) manufacturing process to direct deposit a nickel alloy structural jacket and manifolds onto an SLM manufactured GRCo chamber and nozzle
- Demonstrate the process for integrating the engine system by performing a hot fire, resistance test.

QUANTITATIVE IMPACT

- Order of magnitude savings of cost and schedule
- New competitive markets for Cu Alloys
- New material property database and processes to implement AM into manufacturing processes

PROJECT GOAL

- Develop material properties and characterization of GRCo
- Optimize SLM for GRCo
- Optimize EBF3 to deposit Ni onto GRCo
- Demonstrate the integrated process via hot fire test

- Rocket Engine Propulsion Elements are typically high cost and have long manufacturing times
- No data exist for Additive Manufacturing of Cu alloys
- US government is sole user of engines from sole provider

- AM can significantly reduce development time and cost of complex rocket propulsion hardware
- GRCo material shows high promise for engine component use



STATUS QUO

NEW INSIGHTS



Additive Construction for Mobile Emplacement (ACME) Penta

PROBLEM / NEED BEING ADDRESSED

NASA lacks in-space construction capabilities and cannot fabricate Deep Space mission infrastructure. This technology directly addresses the NASA Advanced Manufacturing **subject matter areas of additive manufacturing, robotics and non-metallic materials processes.** (TA 12, TA04, TA07, TA09)

PROJECT DESCRIPTION/APPROACH

- Several **construction tasks** will be necessary to achieve safe and productive conditions for extended robotic & human presence at extraterrestrial sites
 - Roads, landing pads, berms
 - Unpressurized shelters for protection of rovers, etc.
 - Pressurized shelters for long-term crew protection



- The proposed work will establish the body of knowledge required for co-robotic Additive Construction **of in-space radiation shielding (flight & surface) and infra-structure for human settlement**, with research in 3 major categories:
 - Robotic control & coordination**
 - Materials, processes, and system modeling**
 - Construction tooling and robot testbeds**

QUANTITATIVE IMPACT

- Reduce mass of materials** that must be transported to the space destination by a factor of 2,000:1
- Mitigate space radiation effects on humans** full (SPE/GCR) protection while in a regolith shielded shelter in-space & surface
- Reduce cost** of large scale Earth construction by 10:1

PROJECT GOAL

- Construct a 4 meter diameter demonstration domed structure (habitat, radiation shelter, heat shield) on terrestrial and planetary analog sites**
- Develop regolith based structural materials & print process combinations functional in space environment analog & vacuum testing (TRL 6)
- Prototype a regolith print head for emplacement
- Use existing NASA GCD robots to position and follow tool paths with the regolith print head end effector

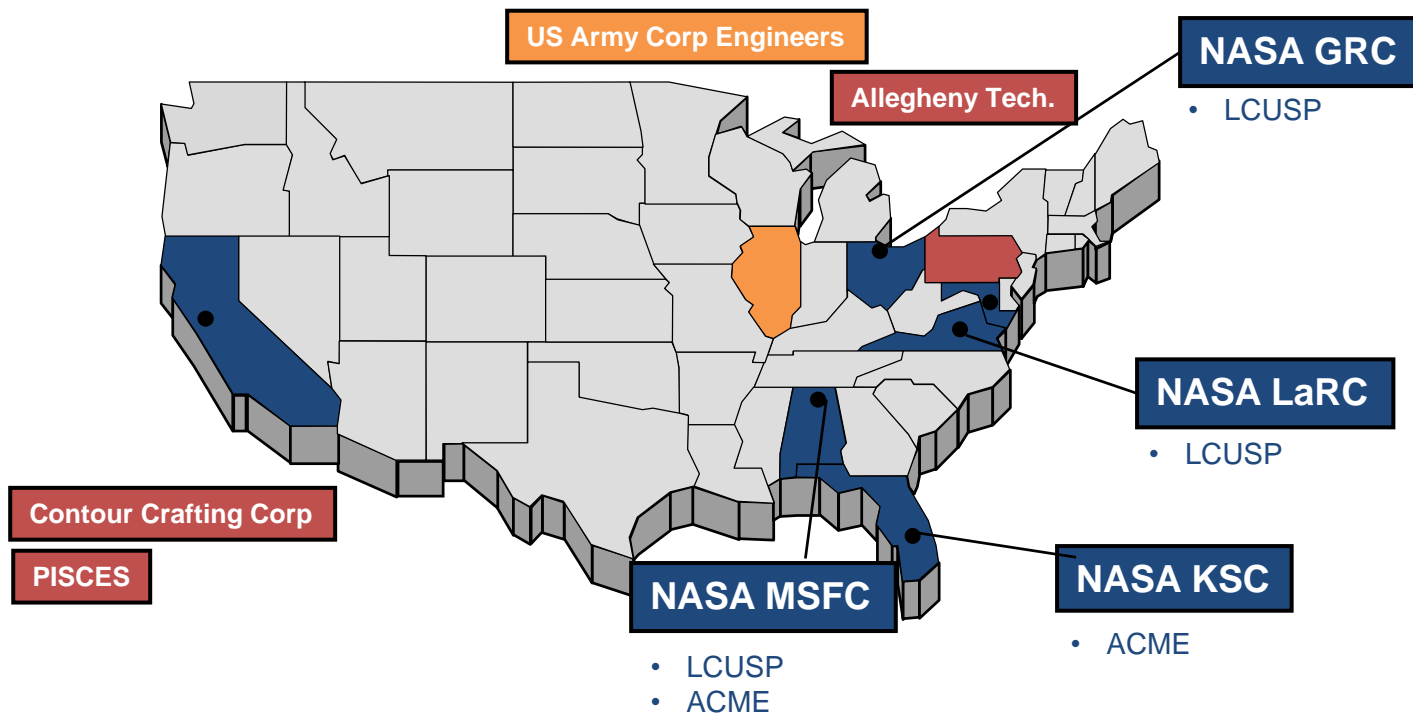
- Large structures for habitats and infrastructure on Earth require substantial form work and/or manual labor**
- Terrestrial applications of this technology are being investigated by the Army Corps of Engineers**
- Space Habitats and infrastructure must be transported from Earth at high cost and low packaging volume**
- 3D additive construction has been completed in the lab using terrestrial materials (TRL 4)**
- Regolith based materials Additive Construction is at TRL 3**



- New regolith based structural materials** can be created in-situ using sintering, sulfur binding, polymer binders, thermite self sintering, synthetic biology binders and more methods, to be developed.
- New robotic technologies** and digital manufacturing allow additive construction on a large scale



AMT Organization and Key Members



Industry Partners

NASA Center
Academia
Industry
Other Gov Ag

MI	MGI	LCUSP	ACME
		<ul style="list-style-type: none"> Allegheny Technologies Inc., Pennsylvania (GRCop Powder) 	<ul style="list-style-type: none"> PISCES - Hilo, HI USACE – Champaign, IL CCC – Marina del Rey, CA



AMT EPO / Conferences



- AMT projects were represented at the NASA Innovation Day held at MSFC on 11/1/2016.
- The ACME materials work was presented at the Advanced Materials for Transformative Changes to the Defense, Aerospace, and Civil Environments conference at the University of Mississippi on 11/16/2016.
- LCUSP presented papers at Joint Army-Navy-NASA-Air Force (JANNAF) in Phoenix, AZ. (Dec 5-8)
- Inside 3D Printing Conference and Expo in San Diego, CA on 12/14 - 15/2016.